
Spectrum Planning and Assessment

NTIA is responsible for managing the Federal Government's use of the radio spectrum. Part of this responsibility is to establish policies concerning spectrum assignment, allocation, and use. ITS supports these requirements by performing spectrum measurements and studies. These measurements and studies are directed toward the goals of assessing current and future spectrum use; identifying existing and potential electromagnetic compatibility (EMC) problems among telecommunication systems belonging to Government and private-sector organizations; providing recommendations for resolving EMC conflicts that may exist in the radio spectrum; and recommending changes in spectrum use to promote spectrum efficiency and improve spectrum management procedures. The Institute's spectrum analyses are directed toward ensuring that increasingly crowded radio spectrum is used with maxi-

mum efficiency, allowing current users to accomplish their missions while finding ways to accommodate new users, services, and technologies.

ITS also provides technical support and guidance for NTIA in the development and advocacy of the United States' position at international spectrum allocation conferences. Decisions made in these international bodies significantly affect spectrum allocations and use both in the United States and worldwide. Major impacts occur in such areas as U.S. export markets and interoperability of global communication systems.

ITS uses its technical expertise to develop new software and hardware for support of Federal Government spectrum management. Many of these products are useful to the private sector, and are available to the private sector on a reimbursable basis.

Areas of Emphasis:

ITU-R Activities

The Institute helps to develop international standards on radio spectrum operations and specific radio systems through participation and chairmanships in the working groups of the International Telecommunication Union-Radiocommunication Sector. Projects are funded by NTIA.

Domestic Spectrum Analysis

The Institute assists in the development of national radio spectrum policies by assessing current spectrum use, predicting future spectrum requirements, and analyzing the impact of new radio technologies and services. Projects are funded by NTIA and the Department of Transportation (DOT).

Radio Spectrum Surveys

The Institute performs usage measurements across a wide range of radio frequencies and geographic locations. This information is used to determine trends in spectrum crowding and to identify spectrum that might be used to provide new services. Projects are funded by the Department of Defense (DOD), DOT, and NTIA.

Spectral Assessment of Government Systems

The Institute performs emission measurements on radio systems as required to verify proper operation, identify and mitigate interference, and develop techniques for improving system electromagnetic compatibility characteristics. Projects are funded by DOD and NTIA.

Radio Frequency Interference Monitoring System

The Institute provides expertise in spectrum measurement systems to other Government agencies by designing and developing spectrum measurement capabilities. Projects are funded by the Federal Aviation Administration.

ITU-R Activities

Outputs

- Preparation of technical standards and recommendations supporting U.S. positions at radio conferences.
- Leadership of U.S. participation in key ITU-R study groups.
- Coordination of U.S. positions on issues related to ITU-R recommendations.

The International Telecommunication Union-Radiocommunication Sector (ITU-R), formerly the International Consultative Radio Committee (CCIR), is the ITU body responsible for developing international standards (ITU-R recommendations) for radio systems. The United States supports the efforts of the ITU-R to ensure compatibility between radio systems operating in this country and those operating in neighboring countries, and to promote commerce by providing telecommunication system standards that U.S. companies can use to develop products for international markets. The Institute provides leadership and expertise in the development of the recommendations, both to support U.S. interests and to ensure high-quality, worthwhile international radio system standards.

The international growth in telecommunications technology and the demand for communication services has compelled the ITU to provide more timely information and standards. In the past, the introduction of new telecommunication services would take years of research and development; now faster development and implementation is required. Communication service providers are anxious to develop new services, provide alternative forms of competition, and let the marketplace determine the fate of new services.

To meet the demand for international standards, the ITU-R has divided its work program into study groups that develop recommendations. As study groups meet infrequently (with some only meeting every 2-4 years), each study group is subdivided into working parties and task groups that provide a continuous forum for the development of recommendations on particular issues for the study group.

The ITU-R is comprised of eight study groups; the first two consider spectrum utilization and propagation issues and the latter study groups manage service-oriented issues (see the Table).

Study Groups of the ITU-R

Study Group	Area of Concentration
1	Spectrum management
3	Radio wave propagation
4	Fixed-satellite service
7	Science services
8	Mobile, radiodetermination, amateur, and related satellite services
9	Fixed service
10	Broadcasting service - sound
11	Broadcasting service - television

Just as international study groups of the ITU-R address specific radio system technologies, the United States has a corresponding set of national committees that prepare U.S. documents for consideration by the international committees. The particular topics treated by each study group vary to meet current needs and to reflect the topics that will be discussed at forthcoming radio conferences. The recommendations of the ITU-R are used to establish technical criteria that are the basis for spectrum allocation decisions and spectrum use, both globally and regionally. In addition, the agreements reached at the World Administrative Radio Conferences become international treaties for the United States. Therefore, it is important to the United States that ITU-R documents accurately reflect the U.S. position on important spectrum policy matters.

ITS is an active participant in both international and national committee work. One ITS staff member holds the office of international chairman of a working party and several ITS staff participate in the committee meetings of the international study groups. Two ITS staff members are U.S. study group chairmen and other ITS staff members participate in U.S. study groups' activities. One ITS staff member is an international rapporteur on short-path radio wave propagation issues relating to the service needs of systems such as personal communications services and wireless local area networks.

The following illustrates how ITS, other Federal agencies, and private industry contribute in the area of radio propagation, which is the specialty of Study Group 3. To properly model the total effect of the atmosphere on an RF propagation link, rain and atmospheric absorption must be considered. In particular, water vapor plays a significant role in the atmosphere's absorption characteristics. For this reason, it is essential that global statistics of water vapor are maintained for individuals who lack the benefit of locally measured distributions. ITU-R recommendation P.835 notes that the distribution of water vapor in the atmosphere may be approximated by

$$\Delta(h) = \Delta_0 \cdot \exp(-h/h_0)$$

where Δ is the water vapor, h is an arbitrary height above the surface in km, and h_0 is a scale height of 2 km. This relationship may be integrated from $h=0$ to $h=6.4$ to find an empirical relationship between path and surface conditions represented by

$$P = 2\Delta_0$$

where P is the total precipitable water along the vertical path in mm. The results indicate that, given total precipitable water, surface water vapor may be derived by dividing by a factor of 2. In order to validate this assumption, data from several sites with 5-10 years of twice daily radiosonde measurements were collected. The data extracted from the radiosondes included total precipitable water and surface water vapor density. Within the United States, the National Aeronautics and Space Administration, the National Oceanic and Atmospheric Administration, and two commercial companies (Science and Technology Corporation and Stanford Telecom), have collected and analyzed water vapor data to produce scatter plots such as those shown in Figures 1 and 2. The data validate the empirical relationship and provide new material that may be used by the ITU for worldwide propagation prediction methods. ITS aids in the development of input documents, which provide the data from measurement and analysis campaigns such as this, to modify or prepare new ITU-R recommendations.

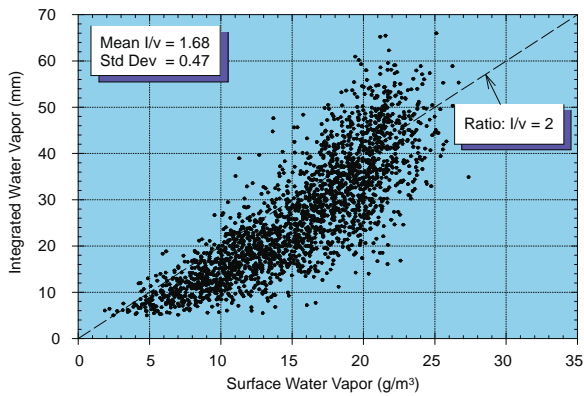


Figure 1. Scatter plot of water vapor data from Kennedy Space Center, Florida.

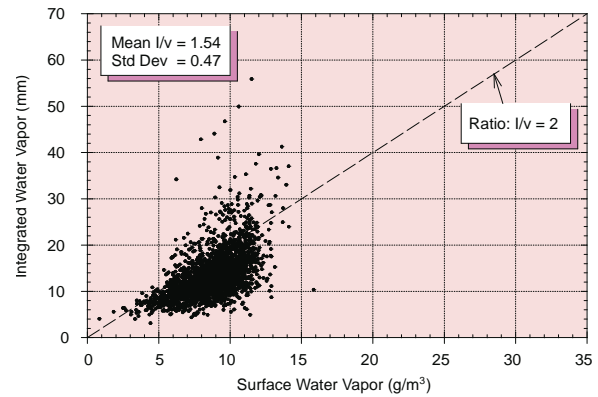


Figure 2. Scatter plot of water vapor data from Oakland, California.

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Domestic Spectrum Analysis

Outputs

- Participation in the Federal Law Enforcement Wireless Users Group and the Public Safety Wireless Advisory Committee.
- Assistance to the Federal Communications Commission in technical studies of high-definition television.
- Investigation of alternative mobile radio architectures.

The year 1996 may be the year of big decisions for Government mobile radio systems. ITS has actively supported a technical basis for making the best possible decisions in areas being considered by several national committees. The Federal Law Enforcement Wireless Users Group (FLEWUG) is a committee of Federal representatives concerned with designing a joint Department of Justice/Department of Treasury nationwide law enforcement radio network. Presumably, many other Federal agencies would want to use this system, possibly as a replacement for their present single-agency systems. The Public Safety Wireless Advisory Committee (PSWAC) is a committee that is planning to ask the Federal Communications Commission (FCC), at the request of Congress, for a block of radio frequencies in which to build the next generation of state and local public safety radio systems.

Both of these committees are describing next-generation radio networks involving billions of dollars of public funding. PSWAC, for example, is currently asking for radio spectrum worth as much as \$30 billion. An analysis of the PSWAC request suggests that it is based on the use of traditional long-range radio architectures to meet high-density traffic requirements in large urban areas. However, most modern radio systems designed to serve dense urban areas (e.g., cellular phone and personal communications services; PCS) have used short-range architectures, which require much less radio spectrum.

ITS has been working actively with PSWAC; the Institute specifically has suggested more modern approaches to radio communications using less spectrum and providing service at less cost. ITS has been

examining whether public safety communications needs could be met by existing spectrum-efficient systems that have proved immensely usable in all other areas of national activity. The use of short-range systems in urban areas possibly could reduce spectrum needs to 10% of the present estimate, as well as providing other significant benefits.

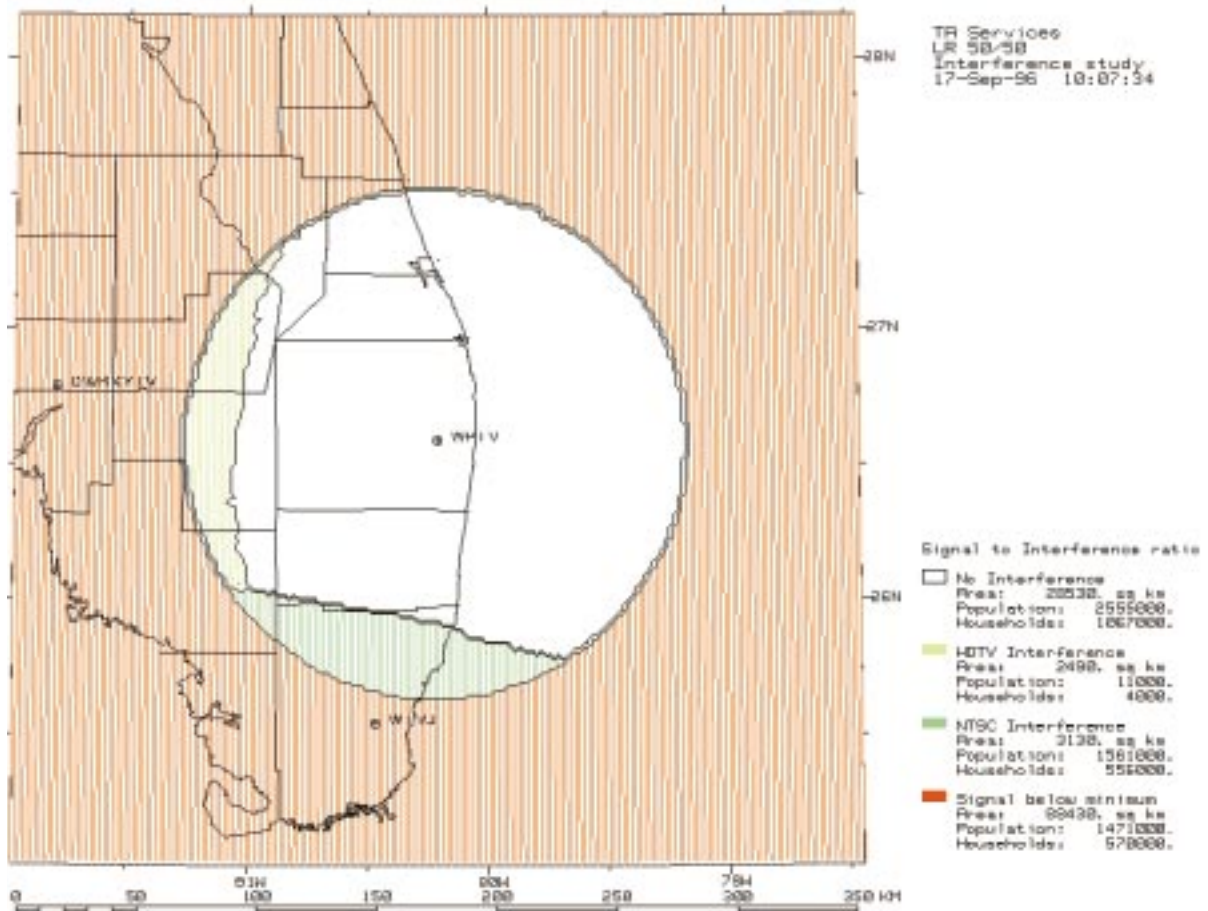
The FLEWUG's challenge is to provide greatly improved services at a lower cost by sharing a common system with many different agencies. In addition to providing a single system with greater capacity and coverage, a shared system might provide greatly improved interagency communications during natural disasters and other emergencies. However, a shared network would provide substantial administrative, technical, and operational challenges for the user agencies. ITS is examining the problems and advantages of such shared networks, so that such networks can be recommended for national systems, if appropriate.

In conjunction with the FCC, ITS is studying how best to provide a high-definition television (HDTV) channel for each existing NTSC television station. ITS will use improved interference modeling programs to verify FCC calculations of coverage and interference. These calculations may have great importance for future decisions on advanced television broadcasting, since television broadcasters believe HDTV coverage must be at least as good as their existing NTSC coverage.

The Figure shows an example of calculations of coverage for station WPTV in southern Florida and a proposed HDTV channel. Two almost coincident circles show that the areas of adequate signal strength are almost identical (and that the terrain is almost flat). In this example, there are two colored areas inside the circular coverage areas of the NTSC and HDTV stations. The green area shows where the existing NTSC station is not adequately received because of a co-channel-interfering signal from existing station WTVJ in Miami, Florida. The yellow area shows where the proposed HDTV station would receive interference from a proposed station (DWRKY-TV) further west. Although these two interference-limited areas have about the same area (2,460 vs. 3100 km²), they have much different pop-

ulations (9,000 vs. 1,527,000 people), since the green area includes heavily populated Miami suburbs. Hence, in this example, the proposed HDTV station would benefit from an increase, compared to the existing NTSC station, of more than 1.5 million potential interference-free viewers.

The example shows computations for a single station. Massive studies involving the set of all existing television stations are required, as well as optimizing strategies, to provide answers about how many television channels are needed to provide all existing broadcasters with matching HDTV channels.



Example of HDTV coverage analysis.

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Radio Spectrum Surveys

Outputs

- Channel-by-channel usage statistics and maximum, minimum and average spectrum occupancy levels in mobile radio bands before, during, and after the 1996 Summer Olympic Games.
- Results of San Diego, California broadband spectrum occupancy survey measurements.
- Environmental radio noise measurements in the HF spectrum.

As part of the ongoing NTIA mission to manage Federal spectrum and assess current and future trends in spectrum use, ITS routinely performs broadband spectrum occupancy measurements at selected locations. The results of these measurements are provided to the Office of Spectrum Management (OSM) in the Department of Commerce, to spectrum management offices in other

Federal agencies, and sometimes as publicly available NTIA Reports. Spectrum surveys can be performed for sponsors in other Federal agencies and private industry on a reimbursable basis. Spectrum survey measurements help identify crowded spectrum and spectrum that can be used for new technologies and services. In 1996, ITS used both the radio spectrum measurement system (RSMS) and several compact radio spectrum measurement systems (CRSMS's) to perform spectrum surveys for OSM and the U.S. Army.

The largest 1996 spectrum survey was performed in Atlanta, Georgia, before, during, and after the 1996 Summer Olympic Games. Figure 1 shows the view of Atlanta from an ITS measurement location. The purpose of this survey was to determine the impact of a major spectrum-loading event on levels of channel use in land mobile radio (LMR) bands. LMR bands between 138 and 940 MHz were measured. The ultimate goal was to determine the maximum



Figure 1. View of downtown Atlanta from a CRSMS measurement site. Located on a high-rise rooftop, this monitoring system was one of three that measured spectrum occupancy and usage during the 1996 Summer Olympic Games (photograph by F.H. Sanders).

crowding that would be expected to occur in LMR bands in an emergency situation. The Olympic Games involved an unprecedented level of use of radio communication systems, and thus provided an excellent opportunity to measure such emergency LMR use levels.

RSMS and two CRSMS units were deployed at three sites in the Atlanta area. These systems ran continuously in a fully automated mode from one week before the Olympics until two weeks after the Games ended. Measured channel usage statistics indicated the percentage of time that each LMR channel was occupied at each measurement location.

Occupancy data (maximum, minimum, and average received spectral power levels) were acquired simultaneously in the LMR bands. An example data graph is shown in Figure 2.

Spectrum survey results are often made available to the public as NTIA Reports. In 1996, data from the 1995 spectrum survey in San Diego, California were released as such a report (see Recent Publications, below). An NTIA Report on the Atlanta, Georgia usage measurements will be published in FY 97. A spectrum survey also was performed for the U.S. Army in 1996. Noise was measured in HF bands at selected locations using CRSMS units.

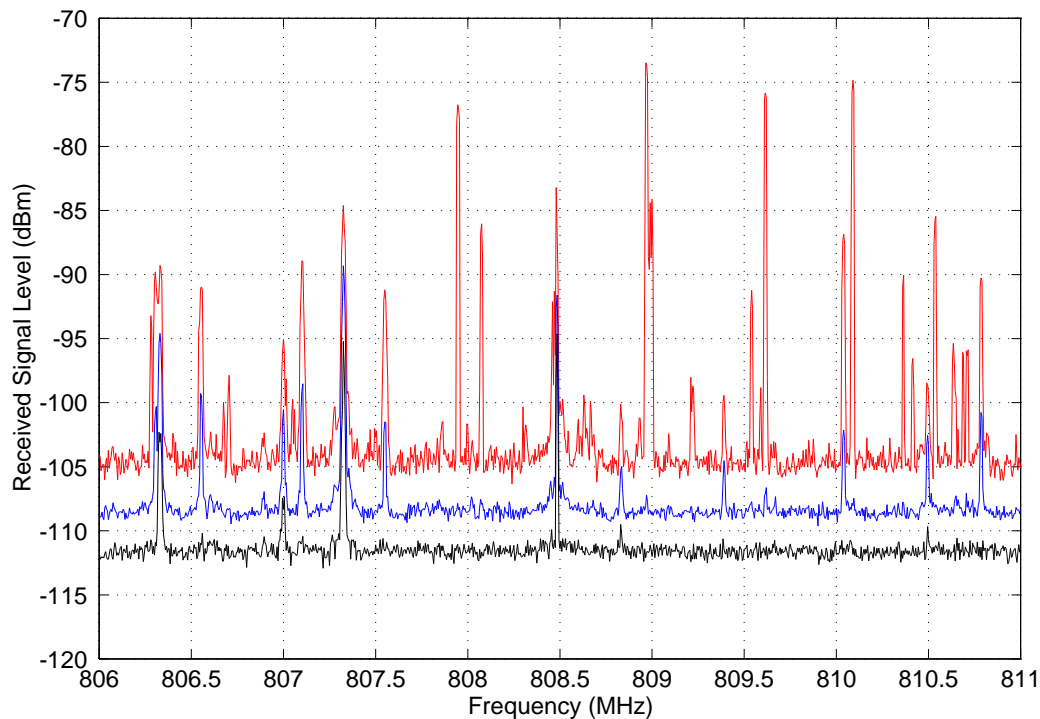


Figure 2. Land mobile spectrum occupancy data from one of the Atlanta 1996 Olympic Games measurement sites. Maximum, minimum, and average received power levels are shown for the period of the Games. Channel-by-channel usage statistics were measured simultaneously with these occupancy data.

Recent Publications

F.H. Sanders, B.J. Ramsey, and V.S. Lawrence, 1996, "Broadband spectrum survey at San Diego, California," NTIA Report 97-334, Dec. 1996.

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Spectral Assessment of Government Systems

Outputs

- Resolution of an ongoing interference conflict between radars and earth stations on the Pacific Coast.
- Measurements and tests to determine the electromagnetic compatibility between existing maritime radios and new radios that use channels half as wide.
- Electromagnetic compatibility measurements for another agency to determine the possibility of locating new satellite facilities at a location with previously installed facilities.

As more users and services attempt to use existing spectrum, accurate measurements of emissions from radio and radar systems have become critical to determining the sources of existing and potential electromagnetic compatibility (EMC) conflicts.

EMC conflicts are commonly manifested as interference; part of the Institute's mission is to support NTIA in the elimination of EMC conflicts involving Government systems. To achieve this goal, ITS maintains measurement capabilities that are tailored to analyze and resolve EMC conflicts (Figure 1). In 1996, the Institute worked with the Office of Spectrum Management (OSM), the Department of Defense, and private-sector radio manufacturers to assess emissions from Government systems and eliminate existing and potential EMC conflicts.

Some increase in interference has been due to the introduction of new technologies, such as digital replacement of analog systems. Other conflicts have arisen due to the introduction of susceptible communication systems into spectrum adjacent to high-power, broadband emitters such as radars. Both conflicts were found to be occurring when, in 1996, teams from ITS, OSM, and the Department of Defense engaged in a joint effort to determine the



Figure 1. Electromagnetic compatibility measurements in progress on board a boat in Tampa Bay. The measurements determined interference characteristics of new maritime radios that operate with channels only half as wide as currently available radios (photograph by F.H. Sanders).

nature of frequent interference from radars to satellite earth stations on the U.S. West Coast (Figure 2). The interference sources were positively identified; tests conducted by the teams also determined that the only technically feasible method for mitigating the interference was to alter the operating procedures for the type of radar involved. New operating procedures have been specified for these radars.

As a follow-up to the West Coast tests, detailed measurements were performed by ITS on this radar type on the East Coast. The measurements, conducted with the assistance and cooperation of the Department of Defense and the radar manufacturer, showed that the radar type met the radar spectrum engineering criteria. This was a significant finding; it meant that EMC conflicts can occur even if all applicable technical standards for emissions have been met.

Attempts to use spectrum more efficiently, such as dividing the channels in mobile bands in half (so as

to achieve twice as many channels in the same amount of spectrum) can create new EMC conflicts because the new equipment must be economical to procure, but must also operate within stricter spectrum tolerances than older equipment. In 1996, the Institute performed measurements jointly with OSM on prototype narrowband maritime radios. The test results showed the technical specifications that the narrowband radios will have to meet if EMC conflicts with other marine radios are to be avoided.

The Institute also contracted with a Department of Defense agency for an EMC study to determine the feasibility of deploying a new earth station at an overseas location where another earth station for a different service already exists. Measurements on emissions from an existing station were performed at White Sands, New Mexico; analysis was subsequently performed in Boulder, Colorado. The results showed that the stations could operate together compatibly, if certain conditions for physical separation and antenna gain limits were met.

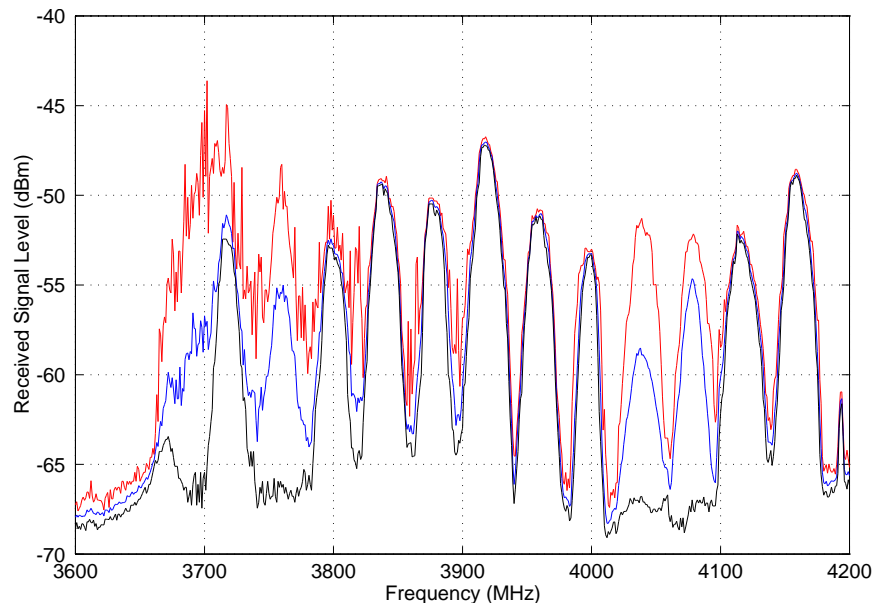


Figure 2. Cumulative graph of data scans recorded at an earth station during an interference event. Curves show maximum (red), minimum (black), and average (blue) signal levels. Desired signals are smooth curves; interference is superimposed on these curves as a rough, maximum-level curve between 3660-3800 MHz.

Recent Publications

F.H. Sanders, R.L. Hinkle, and B.J. Ramsey, 1996, "AEGIS radar emission spectrum characteristics," NTIA Technical Note 96-1, Aug. 1996.

F.H. Sanders, B.J. Ramsey, and V.S. Lawrence, 1996, "Broadband spectrum survey at San Diego, California," NTIA Report 97-334, Dec. 1996.

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Radio Frequency Interference Monitoring System

Outputs

- Hardware and software designs.
- Integrated vehicle design drawings, documentation, and lists.
- Measurement control system integration description, definitions, and flowcharts.
- Integrated electronic package documentation, description, definitions, and detailed drawings.

The ITS radio spectrum measurement system (RSMS) has been used for many years to support spectrum management tasks for the Department of Commerce and other Federal agencies. When the Federal Aviation Administration (FAA) decided to develop a fleet of mobile radio frequency measurement systems, named the Radio Frequency Interference Monitoring System (RFIMS), they selected ITS to design and build the systems.

As part of this three-phase project, the RFIMS program team is (1) analyzing FAA requirements and developing a custom radio spectrum measurement system; (2) designing, building, and testing a prototype mobile system; and (3) integrating and testing production mobile systems. Also as part of this program, ITS will plan and manage associated support requirements, including documentation and training. Software management, development, and documentation play a critical role in all three phases.

Each task includes three areas of system design: the vehicle, the integrated electronic package (IEP), and the measurement control system (MCS). During the first phase, now completed, ITS assessed requirements, evaluated options, and developed an RFIMS specification. ITS personnel analyzed FAA requirements and selected the optimal design features to meet those needs. The vehicle will be a standard van with three 6-ft custom racks in the interior. The mechanical aspects of the vehicle, the electrical generation system, heating and air conditioning, communications equipment, interior arrangement of

equipment racks, seating, and equipment storage have been specified.

The IEP is an integrated set of radio measurement and signal test equipment that performs both specialized measurements and general spectrum monitoring. The IEP consists of three subsystems: the measurement antenna package, the tower-top preselector, and the rack-mounted equipment. The antenna package includes several antennas, chosen to cover the frequency range and measurement needs of the FAA. All are mountable on a pan/tilt platform on a telescoping mast. The tower-top preselector enhances the sensitivity, selectivity, and dynamic range of the measurement system. All other electronic equipment in the vehicle will be rack mounted. Figure 1 shows the rack layout of the vehicle. User comfort, frequency of equipment use, accessibility of the equipment front and rear panels, and experience gained from previous ITS vehicles were all considerations in the rack layout design. IEP design deliverables included the basic measurement system hardware, selection of specific equipment, and calibration hardware.

Many of the standard measurements and spectrum-monitoring requirements dictate the need for automated control of components to ensure the standardization of the measurement technique. Others require a measurement algorithm that cannot be implemented without automated control. In both cases, a control system is required for consistent recording of measurement results. ITS is producing the MCS that will control the measurement system and record the measurements. MCS deliverables included the selection of computer hardware and system software, the preliminary design of measurement routines applicable to specific FAA equipment and problem resolution situations, system calibration (that could be modified by FAA personnel), software documentation manuals, and on-line help files. The system will be able to operate in automatic mode (via local computer) or manual mode (via the instrument front panel controls.) Ease of use is a primary software requirement of the FAA. Figure 2 shows the preliminary design of the main window of the RFIMS.

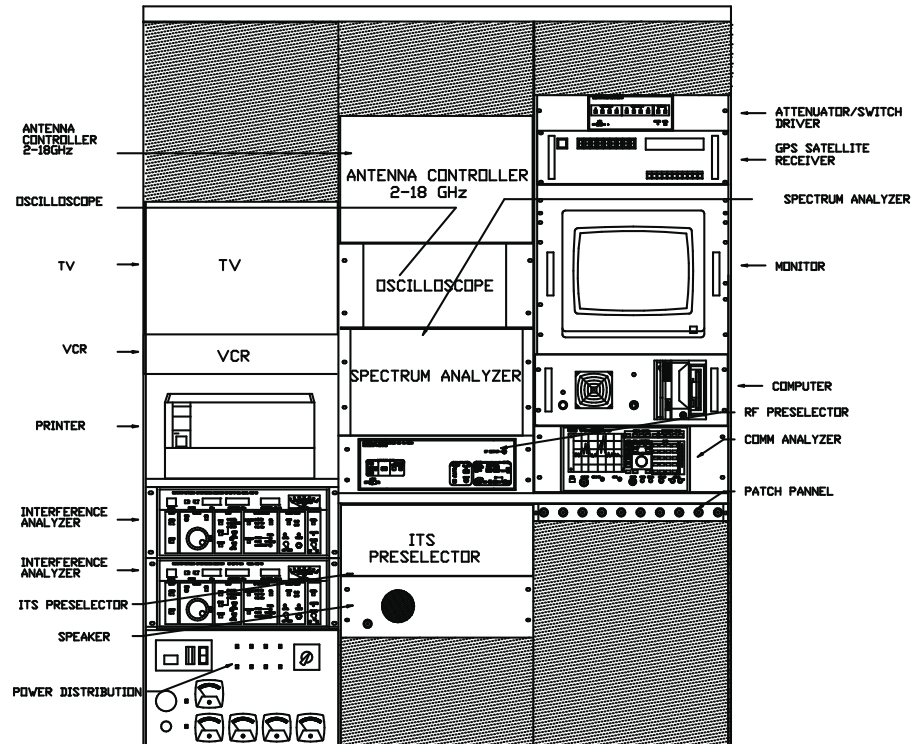


Figure 1. RFIMS rack-mounted equipment layout.

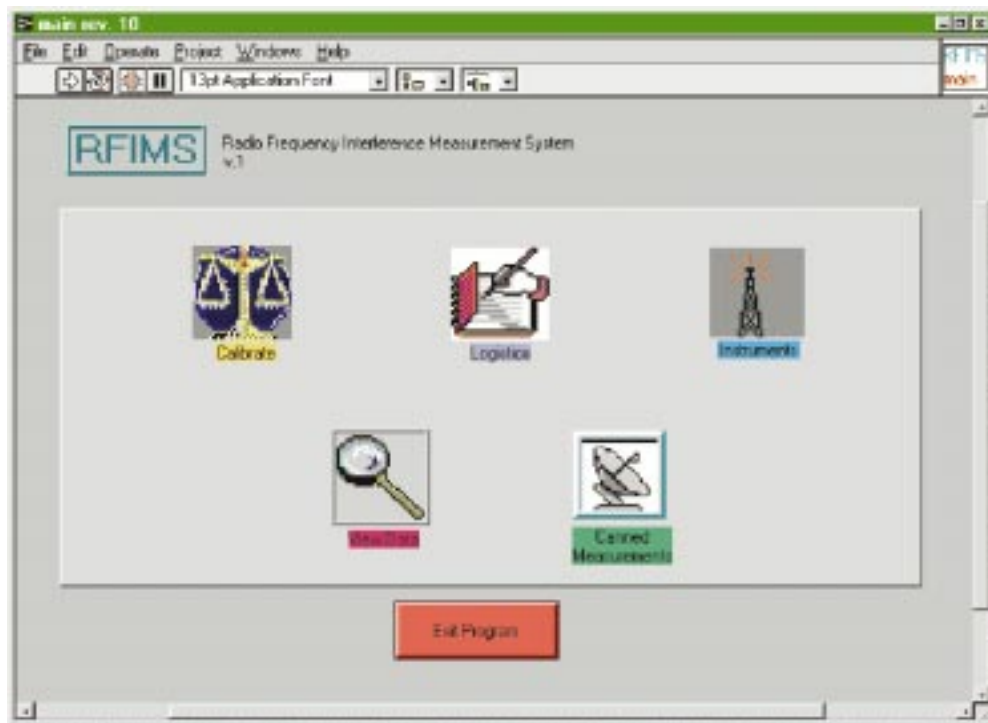


Figure 2. Software main window of the RFIMS.

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